

## Satellite Detection of Ebola River Hemorrhagic Fever Epidemics Trigger Events

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Compton J. Tucker and Jorge E. Pinzon

Ebola hemorrhagic fever, named after the Ebola River in Central Africa, first appeared in June 1976, during an outbreak in Nzara and Maridi, Sudan. In September 1976, a separate outbreak was recognized in Yambuku, Democratic Republic of the Congo (DRC). One fatal case was identified in Tandala, DRC, in June 1977, followed by another outbreak in Nzara, Sudan, in July 1979. Ebola hemorrhagic fever outbreaks results in a very high mortality of patients who contract the disease: from 50 to 80% of infected people perish from this highly virulent disease. Death is gruesome, with those afflicted bleeding to death from massive hemorrhaging of organs and capillaries.

The disease was not identified again until the end of 1994, when three outbreaks occurred almost simultaneously in Africa. In October, an outbreak was identified in a chimpanzee community studied by primatologists in Taï, Cote d'Ivoire, with one human infection. The following month, multiple cases were reported in northeast Gabon in the gold panning camps of Mekouka, Andock, and Minkebe. Later that same month, the putative index case of the 1995 Kikwit, DRC, outbreak was exposed through an unknown mechanism while working in a charcoal pit. In Gabon, two additional outbreaks were reported in February and July, 1996, respectively, in Mayibout II, a village 40 km south of the original outbreak in the gold panning camps, and a logging camp between Ovan and Koumameyong, near Booue.

The largest Ebola hemorrhagic fever epidemic occurred in Gulu District, Uganda from August 2000 to January 2001. In December 2001, Ebola reappeared in the Ogooue-Ivindo Province, Gabon with extension into Mbomo District, The Republic of the Congo lasting until July 2002. Since 2002 there have been several outbreaks of Ebola hemorrhagic fever in Gabon and adjacent areas of Congo.

Of interest is the seasonal context and occasional temporal clustering of Ebola hemorrhagic fever outbreaks. Near simultaneous appearances of Ebola epidemics in Nzara, Sudan and Yambuku, DRC in 1976 occurred within two months of each other in two geographic locations separated by hundreds of kilometers involving two separate viral strains (Sudan and Zaire EBO strains). The outbreaks of Taï, Cote d'Ivoire; Mekouka, Gabon; and Kikwit, DRC in late 1994 also occurred within months of each other in three different geographic regions involving two different viral strains (Cote d'Ivoire and Zaire EBO strains). Fifteen years passed between the 1976-9 and 1994-6 temporal clusters of Ebola cases without identification of additional cases.

Despite extensive field investigations to define the natural history of the Ebola hemorrhagic fever virus, the origin and mechanism of disease transmission, from reservoir to humans, remains a mystery. We have used satellite data to (1) investigate the vegetation type(s) associated with Ebola outbreaks and (2) to identify variations in the wet and dry seasons that are directly associated with Ebola outbreaks.

Normalized difference vegetation index (NDVI) time series data is used in this study as proxy for rainfall. These data are derived from measurements made by the Advanced Very High Resolution Radiometer (AVHRR) instruments carried on the NOAA series of meteorological satellites. The NDVI is computed from the red (550-700 nm) and near infrared (730-1100 nm) channels of the AVHRR as  $NDVI = (ir-red)/(ir+red)$ .

A number of studies have shown that monthly NDVI time series shows the vegetation

response to seasonal dynamics of rainfall and evapotranspiration in a wide range of environmental conditions. The NDVI is a surrogate for photosynthetic capacity since it is highly correlated to the absorbed fraction of photo-synthetically active radiation (FPAR) and thus gross photosynthesis. We use the NDVI to infer FPAR that is directly influenced by rainfall, even in tropical forests.

We used singular value decomposition analysis to identify the time series behavior of the NDVI data from the documented outbreak sites of Ebola hemorrhagic fever. Landsat data confirmed that all Ebola hemorrhagic fever outbreaks occurred in either tropical moist forest or gallery tropical forest in a matrix of savanna. This enabled us to restrict our analysis to only areas of tropical moist forest or gallery tropical forest in Africa.

Employing singular value decomposition analysis we identify areas in Africa with exactly the same time series behavior as the documented outbreak areas. Our study has identified the "Hot Zone" of Ebola hemorrhagic fever in Africa. This is the area where our analysis indicates Ebola hemorrhagic fever is endemic, thus directing more study to specifically these areas.

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Compton Tucker  
Code 614.0  
NASA/Goddard Space Flight Center  
Greenbelt, MD 20771 USA  
301 614 6644 office  
301 614 6695, 6699 faxes